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FIRE FIGHTERS VEHICLE TRAINING SIMULATOR

Fire Research Corporation
26 Southern Boulevard
Nesconset, NY 11767

Contract No. F08635-82-C-0419

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14. ABSTRACT

The Crash Fire Rescue Simulator is designed to duplicate all the operations incorporated in the actual vehicle. The system consists of a number of subsystems which operate in real time to fulfill the goal of the design. The subsystems are Driving Simulator, Video System, Environment Simulator, Fire, Smoke, Foam and Lightning. These systems will are described in detail.

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SECTION I
SYSTEM OVERVIEW

The Crash Fire Rescue Simulator is designed to duplicate all the operations incorporated in the actual vehicle. The system consists of a number of sub-systems which operate in real time to fulfill the goal of the design. The sub-systems are Driving Simulator, Video System, Environment Simulator, Fire, Smoke, Foam, and Lighting. These systems will be described in detail in the following paragraphs.

Driving Simulator - The simulation of driving is accomplished by acquisition of seven basic parameters: 1) Brake Pedal Position, 2) Accelerator Pedal Position, 3) Steering Wheel Position, 4) Shift Position, 5) Facing Direction, 6) Velocity, and 7) Time until next update. The Brake, Accelerator, and Shift Position are used to calculate the force that is applied to the rear wheels of the truck. The Steering Wheel Position is used to calculate the turn radius that the truck is experiencing. The force at the Rear Wheels is translated into a scalar velocity by use of the equation F=Ma where the force F was calculated. In the equation the mass M is a constant and the unknown acceleration. "A" is found by using the previous velocity (last update) and the time interval; therefore, $a = \Delta V/\Delta t$. By substituting this equation into the original equation $F=M\,\Delta V/\Delta t$ and solving for the unknown velocity we obtain the desired V desired $= \frac{F}{M}\Delta t$ + V previous.
This velocity is broken down into X and Y components by taking the sine and cosine of the Facing Direction and a constant to derive the Digital to Analog Converter Voltage necessary to drive the gantry motors at the scale speed required. The Scalar Velocity is also used along with the turning radius to derive the angular velocity of the Azimuth Motor. These outputs, X Motor, Y Motor, and Azimuth Motor when updated at the processing speed of the Microprocessor resulted in a smooth flow of velocity and direction changes which accurately translate into gantry motion to simulate the P-4 Crash Rescue Vehicle. The Microprocessor also has time to calculate several other parameters based upon those inputs. These parameters are provided as scaled D/A output voltages which are used by the environmental sub-system.

Video System - The Driving System is designed to move the video cameras around the model board, as previously described. The trick now is to put a camera (actually 5) at the point where the drivers head would be if he were "to scale" on the model board. This means that the camera lense center will be 1 inch off the surface of the board and all cameras will occupy the same physical space. This obvious impossibility is accomplished by miniaturization of the front end lense assembly. Then using mirrors to reflect the image upward prior to it reaching the centroid point and forming an image on a fiber optic bundle.

This image is transfered upward and split into separate channels and then reconstructed on the sensitive area of the CCD Camera. The camera converts the image into Electronic Video signal which is transfered to the Video Projection Television and projected on the 28 foot diameter Screen mounted around the Cab Mock-up.

Environmental Sub-Systems - The Cab Mock-up is a model of the actual vehicle with all dimensional and operational realism built-in. The Screens are placed at a radius of 14 feet from the driver's eye and give 180 degrees of peripheral vision thus providing all of the visual indications which the driver's brain sensing system require to convince him that the Cab is moving rather than the scene. Additional clues to motion and G-Forces are also provided by incorporation of Cab Roll (a function of rotational acceleration) seat foward motion and cab dip (a function of deceleration) which are signals provided by the main microprocessor and are processed into output via two additional microprocessor boards. The additional environmental sub-systems are run off of the microprocessor output which is proportional to RPM, this voltage is used to produce diesel engine sound and vibration.

Fire, Smoke, and Foam - This system is designed to produce realistic scaled smoke and fire for use in foam operations training. The system is designed to be environmentally safe and easy to maintain. The use of Carbon Dioxide (CO2) and Helium (He) allow the system to produce the desired effect with no clean up required. The smoke is produced by injecting liquid CO2 into heated water thus producing CO2 gas with a high content of water ice. This smoke is piped from the heater through tubes to one of the three smoke pits where Helium is injected to insure that the CO2 will rise. Quartz Lamps and colored filters beneath the model board provide coloring which resembles fire under the smoke. The fire and smoke are increased or decreased at the instructor's control panel. The student overhead foam turret controls a miniature nozzle above the probe optics. The simulated foam is produced by cooling liquid CO2 below the ice point and producing a CO2 snow which covers the fire pit area and sticks to the models as real foam does. The ideal property of the CO2 is that in several minutes it sublimes and is dissipated in the atmosphere.

SECTION II
ELECTRICAL SYSTEM

A) GANTRY MOTORS

Gantry Motors are responsible for the X, Y, as well as the Azimuth directions of the system. The gantry motors are DC servo motors - DC tachometer generator units which have been designed to meet exacting requirements. The design basics of the servo motor include permanent magnet field assemblies, low inertia, high continuous and peak torques, Class F insulation, and totally enclosed non-ventilated construction. Each motor has its own controller board which will supply 90VDC to 120VDC power to the motor, and the enable/disable and direction signals are controlled by the 16-bit microprocessor. The gantry motors controllers require 3 phase AC power and there are various on board DC voltage generators. The azimuth motor provides the camera probe 360 degrees rotational capability. The microprocessor is the "brain" of these DC servo motors. It constantly monitors the accelerator pedal, brake pedal, and steering wheel signals in the cab. From these signals, it will go through the math algorithm which utilizes the equation F=Ma to calculate the vector and scalar quantities of the motion to determine direction and speed. The accelerator pedal and steering wheel signals are also used to derive the angular velocity of the azimuth motor. Once the direction and speed are calculated, the microprocessor will send out digital signals to the digital-to-analog converter and then transmit the analog signals to the various input ports of the motor controller boards.

B) COMPUTER SYSTEM

The computer system is based upon a MC68000 16-bit microprocessor which is operated at a system clock speed of 8MHz. The operational program is stored on EPROMS resulting in high reliability associated with embeded systems. The microprocessor interfaces to the peripherals via the synchronization methods DTACK and VPA. DTACK is utilized by fast peripherals where as VPA is used by slow peripherals. The computer interfaces to three 16-bit Digital-to-Analog Converters which provide analog control voltages to the motor control system of the gantry. These are the primary outputs of the computer to control all probe motion in the X, Y and Azimuth directions. The computer also interfaces to three analog-to-digital converters which monitor the gas pedal, brake pedal, and steering wheel signals. These are inputs along with shifter position, (sensed through a switch input) that are used to provide input to the simulation equation which calculates the drive motor outputs. The only other input used for calculation of the equation result is the optical encoder input. This input is interfaced to a counter card which determines actual angular position and is accessed via the data bus

asynchronously to the actual encoder changes. The microprocessor is also responsible for providing inputs which are required by the various other sub-systems.

Engine RPM is provided in an analog scaled value to the vibration sub-system, the sound sub-system and gages in the vehicle and at the instructors console. Vehicle MPH is scaled and an analog output is provided for gages on the instructor's console and within the vehicle and it is also provided to the motion platform interface to simulate off road operation. Vehicle deceleration is provided to the motion platform interface which controls cab dive during braking. The angular acceleration W2 R is also provided to the motion platform interface and controls side to side tilt of the cab. The processor firmware is based upon a real time process loop which determines priority of task execution and off loads most tasks to intellegent peripherals, in this way the computer seems to operate on all parameters simultaneously. The resulting computer algorithm emulates the actual vehicle with no perceptible delays in response.

C) VIBRATION SYSTEM

Vibration System consists of a DC Motor whose speed of rotation varies according to the engine RPM. The DC Motor is mounted underneath the driver's side of the cab with an eccentric weight. The rotation of the motor will cause the cab to vibrate thus giving both the driver and the turret operator in the cab the crash truck vibrational effect. The driver board for the vibration motor receives engine RPM signal in term of voltage from the microprocessor and interprets this signal into vibration speed. As the engine RPM increases the cab will vibrate more.

D) SOUND SYSTEM

The simulator utilizes a sound system that simulates the engine sound of a crash truck. The engine sound of the crash truck is recorded and is matched with the sound generated by the sound system. The sound generator board receives RPM signal from the microprocessor and determines the engine sound level. Therefore, while driving the simulator, the engine sound level increases as the driver puts more pressure on the accelerator pedal. When the vehicle is not moving, and the shifter position is in neutral the sound system will generate engine idling sound. The engine sound level is amplified by a stereo amplifier which is connected to a speaker located underneath the cab mock-up.

E) MOTION PLATFORM

The cab as discussed in other sections is suspended 5 feet off the ground about a joint which allows up and down motion and twist. The up and down motion is controlled by an air cylinder with solenoid valves which are pulsed to allow time measured quantities of compressed air to move the cab. The twisting mo-

tion of the support beam (actually a tube) is accomplished with a linear actuator which causes the cab to tilt side to side. The timing of the pulses to the air cylinders is under control of an 8-bit 1MHz microprocessor which interfaces to the main computer via the analog outputs of MPH and deceleration. The calculations of pulse width come directly from an adjustable constant which scales the deceleration input. When deceleration is maximum the cylinders fully engaged with the vent closed. When deceleration is zero the cylinder is disengaged and the vent is opened. The MPH input is used to simulate bumps on and off the road. It produces sharp impulses to the cylinder in a random manner thus simulating the randomness of normal on and off road conditions. The off road impulses are more severe and occur at a greater frequency than the roadway impulses. The other motion platform degree of freedom is also under the control of an 8-bit microprocessor which interfaces to the main computer via the W2 R lateral acceleration output. This feedback control loop is closed by a position potentiometer within the linear actuator. The microprocessor moves the motor to minimize the difference between the voltage from the main computer and the voltage from the feedback potentiometer. The system is dynamically adjusted to eliminate overshoot and produce a pulse width modulated signal to the actuator motor. Both of these processors operate independently off the main computer and are, therefore, able to run at full speed without slowing the main loop at all.

F) VIDEO SYSTEM

The video system is designed around a Sony Single Chip CCD Industrial Vision Camera.' The small size, lack of alignment problems and stability of CCD with shock and vibration make it ideal for the front end probe. The power for the cameras is provided by a power supply mounted on the gantry carriage and routed through the probe cable to the probe head. The 5 coax cables from the cameras are routed back via that same path and through the gantry cable assembly back to the main control console and the projection televisions. The alignment and placement of the projection televisions is a function of the front end lense assembly, which is discussed in another section. Each projector is set up for a picture which provides a flat horizon to the observer and no overlap between projector to projector which would result in hot spots.

G) GAGE INTERFACE

The gages used inside the vehicle mock-up are the actual components found on the cab of crash truck for realistic simulation. Some gages are automatically driven by microprocessor whereas some of them are controlled by the Training Instructor. The microprocessor puts out digital signal to the D/A converter which drives the gages. Gages such as voltage level, oil level, water temperature are controlled by the instructor by turning the appropriate knobs on the instructor console. All wires and cables for the gages are wired to connectors so that the vehicle mock-up

is easily changeable by unplugging the connectors and plugging them into a different cab.

H) INSTRUCTOR VISUAL DISPLAY UNIT (UDU)

The instructors VDU is the primary input/output device for the system. This allows input of system parameters and a visual indication of computer operation. The output displayed on the VDU alerts the operator to the condition of all inputs and outputs of the computer. This display is used to perform system readiness checks and to troubleshoot any faults which occur. In addition, adjustment to the Azimuth Motor is accomplished using the display.

I) FIRE, SMOKE & FOAM

The fire and smoke system used on the simulator utilizes CO_2 gas to produce the smoke and a rotating colored glass flicker wheel which is placed in line with three 5Ø watt quartz halogen bulbs to produce flame. The rotational speed is maintained by a fixed RPM gear motor. The fire intensity is regulated with a variable AC transformer which supplies voltage to a step down transformer and rectifiers. The quartz halogen bulbs are mounted out of view under the model board and only the red glow of the bulb, the flicker of the colored glass wheel and the turbulent motion of the CO_2 at the model board interface are viewable, all of these yield realistic simulated fire. The foam nozzle at the probe is controlled by a radio control transmitter/receiver similar to those used on model aircraft. The small size and high torque of this unit make it ideal. The side to side, and the up/and down movements of the overhead foam control handle within the cab is interfaced to the position control inputs of the transmitter. The motions within the cab are viewed on the screens as changes in throw distance and direction of the simulated foam. Slew rate and response time are within the necessary perceivable limits to duplicate real time response.

SECTION III
MECHANICAL SYSTEM

A) MODEL BOARD

The model board is a layout of an arbitrary Air Force field. It has two ruinways, a few taxiways, a ramp, administrative buildings and three fire pits. The scale of the model board is approximately 72 to 1 and the dimension is 32 feet long by 14 feet wide. Photo reproduction techniquie is usede for the models of buildings. Stand trees and bushes that are available from model maker suppliers are used for the foliage. Model planes, such as B-52, F-15E, H-53, and C-130 are used to simulate planes crashing. White and blue miniature light bulbs are used as runway landing lights and taxiway lights respectively to simulate night driving.

B) CAMERA PROBE FRONT END ASSEMBLY

The front end lense assembly is designed to equal the angles of view necessary to reproduce a continuous image with no gaps and originating from a single point of view. The lenses are a triplet design mounted in a slide tube for focusing. Single lense tube images intersect with a mirror mounted in the lense block assembly and reflect upward to produce an image plane on the end of a coherent fiber optic bundle. This image is transferred upward to the barrel lense assembly which utilizes achromat lense to produce an image size conversion from the 2mm fiber optic end to the 8mm CCD Camera Sensor. The achromat lenses are selected to minimize spherical and chromatic aberrations to produce a sharp image on the CCD. The probe assembly consists of various components. It contains the lense assembly which holds the five individual lense in position. The actual position of the lense assembly is eccentric to the probe. This is done to match the viewers perspective to the center of rotation of the vehicle. These lenses are then surrounded with a metal lense guard to protect them. Mounted to this guard is the "foam nozzle". It has 2 degrees of freedom: elevation and rotation, and is activated by radio controlled servo motors.

Also mounted to this guard is a quartz halogen light bulb. This bulb simulates headlights for night training. There are five cameras (one for each lense) connected to the probe assembly. This allows probe rotation without damage to the fiber optic. Finally the CO2 hose which constitutes the foam has a hose reel attached to the probe. This reel allows for rotations. This entire assembly is then mounted to the gantry through a large platter bearing.

C) GANTRY

The gantry is a subsystem which allows the probe to "Drive"

around the model board. It has three degrees of motion X, Y, and Azimuth. The X and Y motions are accomplished by wheels (with a semicircular profile) which ride on hardened steel rods. One of the parrallel rods is fixed while its counterpart is floating. This allows for thermal expansion and other factors affecting track alignment. The wheels are driven through toothed belts. The gantry is constructed of steel and aluminum I beams. The model board size dictates that the X Motion tracks are 10 feet apart. This necessitates driving the X wheels at each side of the gantry to avoid "crabbing"! We accomplish this through a cross-shaft supported by a large thin wall tube, bearings, and flexible couplings. The Y-motion platform only spans 3 feet and does not exhibit "crabbing." This platform consists of a triangle with 3 wheels; two are driven.

The azimuth or rotation is again driven by a toothed belt. It is mounted on a beam suspended from the Y-platform. It consists of two large platter bearings made with plastic balls. The video (fiber optics) and power cables are routed inside its central tube. The cameras are mounted on the outside circumference of the central tube. Power leads run out the top and ride on a delrin ring to allow rotation. "Foam" CO2 is connected through a hose reel and pulley system to take up slack. The total number of revolutions is controlled by a turns counter and limit switches. Essentially the system is similar to a large flat bed plotter with an azimut (rotational pen).

D) SCREEN AND PROJECTORS

The screen is 28 feet in diameter by 11 feet high. It consists of seven sections of lightweight composite laminate that bolts together to form a free standing unit. At the merging point between adjacent images there is a narrow black stripe to prevent video overlap.

There are five 400 Lumen output projectors. These projectors are mounted on an adjustable chassis and are placed under the cab in a semi-circular fashion and project on the five segments of the screen. These projectors have a sharp and crisp image, and accept the projector signals from a wide selection of color and Black & White signals, video sources such as UHF/UHF tuner, and video tape players. Each projector has a cable remote control unit.

E) VEHICLE MOCK-UP

The mock-up is a full scale realistic reproduction of the actual vehicle. The mock-up is constructed of lightweight composite materials to reduce mass so as to allow simulated environmental responses to be applied to the motion platform without excessive power being required. The simulator utilizes actual components where possible in the cab if weight is minimal and interface to the simulator is possible. Gages and controls are prime examples where actual units are attempted to be used. The actual access

doors to the vehicle are not utilized, the instructors station provides entry to the rear of the mock-up. The possibility of several different types of vehicles is allowed by the use of cable connections through the bulkhead of the mock-up and this can provide simulation training of several different vehicle types.

F) INSTUCTOR STATION

Instructor console houses all the control and electronics of the simulator. There is a console to monitor the decisions made by the students on all the controls. It also monitors all the gages reading including the speedometer and RPM readings. The computer and all the electronics are also located in instructor's station. The instructor is able to start the system, set parameters and monitor the computer outputs on the CRT display inside the instructor station. An emergency shutdown switch is also provided and located on the instructor's console and is easy accessible to the instructor. It is a protection given against any failures during operation. Through the glass window in the instructor station, the instructor can observe the student's driving performance on the projector screen.
Also provided to the instructor are the fire/smoke and foam generation controls. Each fire location on the model board has a knob to control the fire intensity, a switch to turn the fire on, and a switch to turn the smoke system on. Therefore, there is a set of control switches for each fire location.

G) MOTION PLATFORM

The visual image of the trainer is supplemented with various cab and seat motions. These motions are essential to obtain realistic sensations associated with and driving and operating a crash truck. All motions are activated by the controls of the vehicle i.e. steering, brake, gas, etc.

Cab roll yields centrifical force associated with vehicle turns. The amount of tilt is controlled by a combination of steering wheel position and vehicle speed. The mechanism consists of a large teflon journal bearing (12" diameter). This bearing is mounted in the center of the main tube with the cab at one end. Roll is implemented by a 24 volt DC linear actuator with feedback. Cab tilt is also accomplished at the journal bearing. The bearing is pivoted on each side perpendicular to its axis.
At the end of the tube (opposite the cab), we have a pneumatic cylinder coupled to a spring. This sub-system yields three motions. Braking, tilt controlled by velocity and brake pedal position. This actuator also supplies two types of random road bumps. The first type is for normal driving and is based on accelerator or gas pedal position. The second type is more severe and is instructor controlled via a potentiometer. It is used to simulate off road driving.

The driver's seat has motion in the forward direction. This mo-

tion is accomplished by a pneumatic cylinder with the seat on two tracks. It is returned to the neutral position by a return spring. This motion has two variations. First it is used for braking in conjunction with tilt. During braking the seat is pushed forward yielding a feeling of being pushed back into the seat due to deceleration. It is controlled by brake pedal position and velocity. The second type of seat motion is to simulate gear shifting in a P-4 Crash Truck. This is a short sharp motion as compared to the slow controlled seat motion that occurs during braking. Shift kicks are controlled by stick shift position only.

APPENDIX A

PRODUCTION COST ANALYSIS

AND

LIFE CYCLE COST ANALYSIS

FIRE FIGHTERS VEHICLE TRAINING SIMULATOR

PRODUCTION COST ANALYSIS

	Qty.	Cost	30% O.H.	$25 Hr. Labor	Total
1. Projectors	5	50K	65K	40 hrs-$1000	66K
2. Legs for Projector	5	5K	6.5K	20 hrs-$ 500	7K
3. Fiber Optics	5	60K	78K	100 hrs-$2500	80.5K
4. Cameras	5	6.75K	8.775K	10 hrs-$ 250	9K
5. Motor Controller	1	10K	13K	20 hrs-$ 500	13.5K
6. Cab	1	65K	84.5K	200 hrs-$5000	85K
7. Cab Support	1	30K	39K	250 hrs-$6250	45.250K
8. Main Gantry	1	15K	19.5K	50 hrs-$1250	20.75K
9. X - Y Gantry	1	10K	13K	100 hrs-$2500	15.5K
10. Triangle for Azimuth and Camera Probe	1	18K	23.4K	40 hrs-$1000	24.4K
11. Slip Rings	1	15K	19.5K	40 hrs-$1000	20.5K
12. Lights		13K	16.9K	40 hrs-$1000	17.9K
13. Computer & Computer Cabinet	1	75K	97.5K	400 hrs-$10000	107.5K
15. Television	1	0.5K	0.65K	1 hr -$ 25	.675K
16. VCR	1	0.5K	0.65K	1 hr -$ 25	.675K
17. Smoke/Fire/Foam 4K 5K	1	9K	11.7K	40 hrs-$1000	12.7K
18. Models and Board	1	15K	19.5K	400 hrs-$10000	29.5K
19. Screens	1	8K	10.4K	100 hrs-$2500	12.9K
20. Curtains	1	2K	2.6K	40 hrs-$1000	3.6K
21. Platform	1	1K	1.3K	80 hrs-$2000	3.3K
22. Instructor's Panel	1	20K	26K	160 hrs-$4000	30K
23. Vibration System	1	5K	6.5K	40 hrs-$1000	7.5K
24. Sound System	1	3K	3.9K	40 hrs-$1000	4.9K
25. Mechanical, Engineering Supervision		60K	78K		78K
26. Electrical Supervision		60K	78K		78K
27. Installation		50K	65K		65K
28. Lenses		10K	13K	40 hrs-$1000	14K

LIFE CYCLE COST ANALYSIS

Items Which May Encounter MTBF During System Life	MTBF (hours)	Quantity	Estimated Labor to Replace (hours)	Approximate Replacement Cost For Each (Labor Not Included)	
1. Projectors	10,000	5	8	$13,000	
2. CCD Cameras	10,000	5	3	1,500	
3. Computer Terminal	10,000	1	1/2	2,200	
4. Fiber Optic	*	1	100	78,000	*Does not wear out, damage due to mishandling.
5. Radio Transmitter	1,000	1	1 1/2	500	
6. Stereo Amplifier	10,000	1	1	200	
7. 12V Batteries	1,000	2	1/2	100	
8. Smoke Machine	1,000	1	1	1,000	
9. Fan Blowers	10,000	3	1	200	
10. Translation Motors	10,000	2	1	4,000	
11. Rotation Motor	10,000	1	1 1/2	4,000	
12. Roll Linear Actuator	1,750	1	1	500	
13. Air Cylinders	1,500	2	1 1/2	200	
14. Solenoids	3,000	4	1/2	150	
15. Drive Belts	4,000	5	1/2	100	
16. Bearings	10,000	12	3	50	
17. High Pressure Hose	1,000	100 ft.	4	400	
18. 500 Watt Quartz Lamps	500	38	1/2	20	
19. 1000 Watt Quartz Lamps	500	8	1/2	50	
20. 1500 Watt Fluorescent Bulbs	500	20	1/2	25	
21. 50 Watt Fire Lamps	500	9	1/2	10	
22. Runway Lights	500	150	1/2	1.50	